3.0 Air Emissions Characterization

3.1 Introduction

The Air Emissions Characterization workgroup performed a review of current literature on emission factors and techniques for the estimation of hydrogen sulfide, ammonia, odor, and particulate matter emissions from AFOs. Emission factor data for each of these pollutants is summarized in Tables 3-1 through 3-4 by pollutant. Inclusion of an emission factor in the tables does not mean that the workgroup is advocating the use of that emissions factor. The intent of the workgroup was to provide enough information for users to choose the best emission factor for a specific situation.

3.2 Purpose

The charge of the Air Emissions Characterization workgroup was to identify emission factors currently available that can be used to estimate emissions of hydrogen sulfide, ammonia, and odor emissions from AFOs.

In addition, particulate matter with an aerodynamic diameter less than or equal to 10 microns (PM_{10}) was studied by the workgroup because fine particulate matter can be a carrier for odor. Additionally, PM_{10} can be easily inhaled by humans, causing adverse health affects.

3.3 Methodology

The workgroup started with seven questions provided by the DNR and added an eighth question of their own:

1. What are the sources of pollutants at an AFO?
2. What source/s contribute the most to the atmosphere?
3. What emission factors are available that accurately characterize emissions from sources at AFOs, and are they applicable to Iowa?
4. What process models are available to characterize emissions from AFOs?
5. What animal types are sources of pollutants and how do they vary?
6. What characteristics of building structures impact the emission of pollutants?
7. What characteristics of waste storage structures impact the emissions of pollutants?
8. What land application types are sources of pollutants and how do they vary?

After a general discussion of these questions, the workgroup decided to focus on emission factors. The workgroup chose not to address the fourth question regarding process models because many process models are currently still in development and because these models were beyond the technical expertise of the majority of the workgroup members.

The workgroup then conducted a literature review of available emission factors. When possible, the workgroup tired to focus on emission factors that had been published in studies included in the “Iowa Concentrated Animal Feeding Operations Air Quality Study” final report of 2002 or published after it was released. The review focused on four pollutants: hydrogen sulfide, ammonia, odor, and particulate matter. Each pollutant was then assigned to either a single individual or small subgroup, and a standardized emission factor table was designed for group use. A draft emission factor summary for each pollutant was provided by each subgroup to the workgroup for review and comment before being finalized.

3.4 Emission Factor Background

There are several ways to estimate emissions from a process. The preferred methods are continuous emissions monitoring, which provides constant measurement of a pollutant, and emissions testing, which provides an exact measurement of a pollutant during a set time period, because these methods are the most representative of the tested source's emissions. However, test data from individual sources are not always available and, even if they are available, they may not reflect the variability of actual emissions over time. Thus, emission factors are frequently the best or only method available for estimating emissions, in spite of their limitations.[1]

Emission factors represent industry averages and show the relationship between emissions and a measure of production. Not all emission factors are created equal. Emission factors that are derived from a large amount of industry-wide emissions testing are given high rankings, while emission factors derived from a single test are given the lowest ranking.

When reviewing the AFO emission factors provided in Tables 3-1 through 3-4, it is important to note that the AFO emissions factors provided generally do not account for climate and geography, diurnal and seasonal emission patterns, feeding practices, animal life stage, individual animal management practices, or pH. The workgroup has added notes, where possible, to indicate the conditions such as type of housing unit, type of animal, season, etc. affecting the emission factor.

Hydrogen sulfide data in Table 3-1 were compiled from sources identified from searches of the National Library of Medicine (Pub Med), through targeted Web searches, and from a number of reports that summarize published literature. The original sources of these data list values in various forms and units. In some cases, details regarding the nature of the livestock facility studied are limited. Thus, in order to determine hydrogen sulfide emission factors in grams per day per animal unit (g/day•AU) assumptions were sometimes made.

Emission factors for ammonia are summarized in Table 3-2. The emission factors are from several studies and include average emission factors calculated by the Environmental Protection Agency (EPA) in January 2004 (shaded in the table).

Emission factors for odor are summarized in Table 3-3. It is important to remember that the definitions of odor units (OUs) and detection thresholds (DTs) vary according to which odor method was used during the study. The odor methods used are listed at the end of Table 3-3. In general, odor units are defined as the volume of diluted (non-odorous) air divided by the volume of odorous sample air at either detection or recognition. Odor units are dimensionless numbers.

Emission factors for PM_{10} are summarized in Table 3-4.

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[1] Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume 1: Stationary Point and Area Sources, Jan. 1995, p. 1.

3.5 How to Estimate Emissions Using an Emission Factor

In general, emissions can be estimated using emission factors according to the following equation:

$$\text{Emissions} = \text{Production Rate} \times \text{Emission Factor} \times ((1 - \% \text{ Control Efficiency})/100)$$

The workgroup did not address control efficiency in their work for this report. Examples of how to use emission factors provided in this report are as follows:

Example #1
Estimate hydrogen sulfide (H_2S) emissions from 1,000 cattle in a feedlot with passive ventilation.

Choose an emission factor that fits this situation from those listed Table 3-1 such as 0.888 g/day · AU. The study from which the emission factor was taken considers 1 feeder cow to equal 1 animal unit. Assume 1 pound equals 454 grams.

$$1{,}000 \text{ feeder cattle} \times \frac{1 \text{ AU}}{1 \text{ feeder cattle}} \times \frac{0.888 \text{ g H2S}}{\text{day} \cdot \text{AU}} \times \frac{\text{lb. H2S}}{454 \text{ g H2S}} = \frac{1.96 \text{ lbs. } H_2S}{\text{day}}$$

Example #2
Estimate ammonia (NH_3) emissions from poultry CAFO, with a size of approximately 20,000 broilers.

Choose an emission factor that fits this situation from those listed in Table 3-2 such as 0.22 lb/year/head. Assume 1 broiler = 1 head.

$$20{,}000 \text{ head} \times \frac{0.22 \text{ lb Ammonia}}{\text{year/head}} = \frac{4{,}400 \text{ lbs. Ammonia}}{\text{year}} \times \frac{\text{year}}{365 \text{ days}} = \frac{12 \text{ lbs. } NH_3}{\text{day}}$$

3.6 Emission Factor Use

Emission factors can be used in emissions inventories and atmospheric dispersion modeling analyses. Inventories provide a method of tracking emission trends over time. Inventories are created by applying emission factors to a set of activity data or production data for a certain time period.

Atmospheric dispersion models are routinely used to estimate the ground level concentration of pollutants emitted into the atmosphere. These models use mathematical representations of physical and chemical atmospheric processes in combination with characterization of air pollutant emissions to simulate the transport and diffusion of pollutants from a source of release. Emission factors are used to estimate the rate that a substance is released into the atmosphere from a source. The Dispersion Modeling workgroup recommends application of the American Meteorological Society / Environmental Protection Agency Regulatory Model (AERMOD)[2] for estimation of odor, hydrogen sulfide and ammonia concentrations from AFOs. To read more about their recommendations, please refer to Chapter 4.0 of this report.

[2] http://www.epa.gov/scram001/7thconf/aermod/aermodug.pdf

3.7 Conclusion

The emission factors in Tables 3-1 through 3-4 are reported by the workgroup with the intent of providing the public with one centralized location to find emission factors that may be used to estimate emissions from AFOs. Users should consider the animal type, housing type, any geographic or seasonal information, and whether the data was peer-reviewed or not. When evaluating emission factors from other countries, users should also consider how the feeding and housing practices in that country differ from those in Iowa. Finally, users should note that using an emission factor to calculate emissions results in an estimation of pollution over a certain amount of time (hour, day, year). It will not provide the concentration of a pollutant in the ambient air.

Table 3-1A: Hydrogen Sulfide Emission Factors - Housing

Livestock	Housing System	Operation Type	Ventilation System	H_2S Emissions	H_2S Emission Factors (lb/day.place)	H_2S Emission Factors (g/day.AU)	Comments	Ref
Swine	CAFO	Finisher	Passive	7.7 ug/sec.m^2	0.00109	1.24	Assumes 8 ft^2/pig	1
Swine	CAFO	Finisher	Passive		0.0015	1.70	June-Sept, deep pitted	2
Swine	CAFO	Finisher	Passive		0.00033	0.375	1000 head, mean rate	3
Swine	CAFO	Finisher	Passive		0.16	182	Deep pitted approx'n based on manure storage facility (Stirred slurry?)	4
Swine	CAFO	Finisher	Mechanical	7.1 ug/sec.m^2	0.00101	1.15	Assumes 8 ft^2/pig	1
Swine	CAFO	Finisher	Mechanical	610 mg/day. m^2		6.71	Cold weather, Building 3B, 1000 head, deep pit	6
Swine	CAFO	Finisher	Mechanical	610 mg/day. m^2		32.3	Warm weather, Building 3B, 1000 head, deep pit	6
Swine	CAFO	Finisher	Mechanical	910 mg/day. m^2		5.89	Cold weather, Building 4B, 1000 head, deep pit	6
Swine	CAFO	Finisher	Mechanical	910 mg/day. m^2		35.9	Warm weather, Building 4B, 1000 head, deep pit	6
Swine	CAFO	Gestation	Mechanical	0.7 ug/sec.m^2	0.00010	0.114	Assumes 8 ft^2/pig	1
Swine	CAFO	Farrowing	Mechanical	5.5 ug/sec.m^2	0.00078	0.888	Assumes 8 ft^2/pig	1
Swine	CAFO	Nursery	Mechanical	45.7 ug/sec.m^2	0.00647	7.34	Assumes 8 ft^2/pig	1
Chickens	CAFO	Broilers	Mechanical	0.2 ug/sec.m^2	0.00000354	0.0587	Assumes 1 ft^2/broiler	1
Cattle	Feedlot		Passive	0.990 kg/yr.m^2	0.00069	0.115	Assumes 40ft^2/cattle	7
Dairy	Freestall		Passive	0.4 ug/sec.m^2	0.00028	0.0332	Assumes 40ft^2/cow	1

Table 3-1B: Hydrogen Sulfide Emission Factors – Manure Storage

Livestock	Housing System	Operation Type	Manure System	H_2S Emission Flux	H_2S Emission Rate (g/system.hr)	H_2S Emission Factors (g/day.AU)	Comments	Ref
Swine	CAFO	Manure storage lagoon	Open lagoon	0.73 ng/sec.cm^2 0.82 ng/sec.cm^2 2.11 ng/sec.cm^2		4.55 Aug. 5.12 Sept. 13.2 Oct.	5400 finisher pigs/yr 2 cycles/yr Lagoon 7800 m^2	9
Swine	CAFO	Manure storage lagoon	Open lagoon A	9.1 +/- 1.6 ug/sec.m^2 (mean +/- 95% CI)		2.80	Apr-Jul 2000, 6 visits 8636 AU 30,735 m^2	5
Swine	CAFO	Manure storage lagoon	Open lagoon B	2.3 +/- 3.2 ug/sec.m^2 (mean +/- 95% CI)		1.95	May-Jul 2000, 6 visits 1252 AU 12,310 m^2	5
Swine	CAFO	Feeder to finisher, mechanically ventilated	Deep pit, under-slat, short term or long term	0.37 ng/sec.cm^2	5.9	(0.052)	13,680 pigs/yr	8
Swine	CAFO	Farrow to finisher, Manure Storage	Earthen concrete, or metal-lined storage basins	1.10 ng/sec.cm^2	12.5	(0.183)	8,200 pigs/yr	8
Swine	CAFO	Feeder to finisher, Manure Storage	Lagoon, without anoxic photosynthetic blooms	0.32 ng/sec. cm^2	22.7	(0.192)	14,170 pigs/yr	8
Swine	CAFO	Farrow to feeder, Manure Storage	Lagoon, with anoxic photosynthetic blooms	0.24 ng/sec. cm^2	16.9	(0.110)	18,500 pigs/yr	8

Animal Units (AU)
Tables 3-1A and 3-1B assume 2.5 swine > 25 kg = 1 AU, 1 feeder cattle = 1 AU. 1 dairy cow = 1.4 AU, 100 Broilers = 1 AU

References for Tables 3-1A and 3-1B

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9. Zahn JA, Tung AE, Roberts BA, Hatfield JL. 2001. Abatement of ammonia and hydrogen sulfide emissions from a swine lagoon using a polymer biocover. J Air & Waste Manage Assoc 51:562-573.

Table 3-2: Ammonia Emission Factors

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Poultry	Dry Layer Houses	-		87	lb/NH3/AU-yr	0.87				Valli et al., 1991	1
		-		41.6 - 74.8	% of N	0.90				Yang et al., 2000	1
		-		AVERAGE		0.89				Calculated by EPA	1
Poultry	Wet Layer Houses	-		110	g/hen/yr	0.24				Kroodsma et al., 1988	1
		-		83	g/hen/yr	0.18				Hartung and Phillips, 1994	1
		-		38.8	kg/500 kg L W	0.31				Hartung and Phillips, 1994	1
		-		AVERAGE		0.25				Calculated by EPA	1
Poultry	Broiler Houses	-		0.065	kg/animal/yr	0.14				Asman, 1992	1
		-		18.5	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		8.9	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		19.8	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		11.2	mg/hr/broilers housed in litter					Groot Koerkamp et al., 1998	1
		-		21.9	g/animal/fattening period					Kroodsma et al. 1998	1
		-		0.1	kg/broiler/yr	0.22				Tamminga, 1992	1
		-		0.15	kg/animal/yr	0.33				Van Der Hoek, 1998	1
		-		AVERAGE		0.22				Calculated by EPA	1
Poultry	Dry Layer	Manure Land Application		7	% of N applied					Lockyer and Pain, 1989	1
	Wet Layer			41.5	% of N applied					Lockyer and Pain, 1989	1
	Broiler			25.1	% of N applied					Cabera et al., 1994	1
Poultry	Houses	-		36.0	% NH3-N loss	0.5				Bowman et al., 1997	3, 4, 5
Poultry	Caged Layers	Winter	VA	8	g NH3/AU-h			192		Wathes et al., 1997	2
		Summer	VA	12.5	g NH3/AU-h			300		Wathes et al., 1997	2

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Poultry	Broilers	Winter	VA	9	g NH3/AU-h			216		Wathes et al., 1997	2
		Summer	VA	9	g NH3/AU-h			216		Wathes et al., 1997	2
		On litter	VA	4 - 20	ug NH3/m2-s			7 -33		Zhu et al., 2000	2
		On litter	VA	18.6	kg NH3/AU-yr			51		Demmers et al., 1999	2
		First flock on new bedding	ST	149 - 314	mg NH3-N/m2-h			4.3 - 9.1		Brewer and Costello, 1999	2
		After four flocks on bedding	ST	208 - 271	mg NH3/m2-h			6.0 - 7.9		Brewer and Costello, 1999	2
		-		0.28	kg-NH3/animal-yr					Battye, et al., 2003	3
Poultry	Laying Hens	On litter	VA	7,392 - 10,892	mg NH3/AU-h			177 - 261		Groot Kooerkamp et al., 1998	2
		Cages	VA	602 - 9,316	mg NH3/AU-h			14 - 224		Groot Kooerkamp et al., 1998	2
		-		0.37	kg-NH3/animal-yr					Battye, et al., 2003	3
Poultry	Turkey Houses	-		0.429 - 0.639	kg/animal/yr	1.18				Asman, 1992	1
		-		0.48	kg/animal/yr	1.06				Van Der Hoek, 1998	1
		-		AVERAGE		1.12				Calculated by EPA	1
Swine	Houses	Lagoon Systems (includes flush houses, pit recharges & pull plug systems)		229.1	mg/head/hr	4.0				Andersson, M., 1998	1
				3.1	kg/animal/yr	6.8				Oosthoek et al., 1991	1
				3	kg/head/yr	6.6				Oosthoek et al., 1991	1
				3.7	kg/finish pig/yr	8.2				Harris and Thompson, 1998	1
				13	lb/1000 pigs/day	4.3				Heber, 1997	1
				AVERAGE		6.0				Calculated by EPA	1
Swine	Houses	Deep-Pit Systems		3.18	kg/fattening pig/yr	7.0				Asman, 1992	1
				10.0 - 12.0	g NH3/animal/day	8.1				Hoeskma et al., 1993	1
				8.0 - 9.0	g NH3/animal/day	6.2				Hoeskma et al., 1993	1
				255	g/hour/858 pigs	5.2				Ni et al., 2000	1
				186	g/hour/870 pigs	3.8				Ni et al., 2000	1
				145	g NH3/500 kg L W-day	12.5				Ni et al., 2000	1
				3	kg/animal/yr	6.6				Oosthoek, et al., 1988	1
				34.9 - 44.6	lb/day/2000 finishing hogs	6.6				Secrest, 1999	1
				13	g/head/day	9.5				USDA, 2000	1
				AVERAGE		7.3				Calculated by EPA	1

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Swine	Lagoons	-		2.2	kg N/yr/head	5.9				Aneja et al., 2000	1
		-		64.7	% of excreted N	17.6				Fulhage, 1998	1
		-		6.53	kg NH3/yr/head	14.4				Koelliker and Miner, 1971	1
		-		77.2	% of excreted N	21.0				Fullhage, 1998	1
		-		8,210	kg/yr/500 AU	14.5				Martin, 2000	1
		-		5,602	kg/yr/500 AU	9.9				Martin, 2000	1
		-		AVERAGE		13.9				Calculated by EPA	1
Swine	Manure Land	Liquid (>2,000 head)		20	% N lost					Calculated by EPA	1
		Liquid (<2,000 head)		23	% N lost					Calculated by EPA	1
		Solid (>2,000 head)		19	% N lost					Calculated by EPA	1
		Solid (<2,000 head)		17	% N lost					Calculated by EPA	1
Pigs	Finishing	-	VA	5,700 - 5,900	mg NH3/pig-day			42 - 43		Aarnink et al., 1995	2
		-	VA	46.9	kg NH3-N/AU-yr			160		Demmers et al., 1999	2
		-	VA	0.9 - 3.2	kg NH3-N/day					Burton and Beauchamp, 1986	2
		on bedding	VA	1,429 - 3,751	mg NH3/AU-h			34 - 90		Groot Kooerkamp et al., 1998	2
		on slats	VA	2,076 - 2,592	mg NH3/AU-h			50-62		Groot Kooerkamp et al., 1998	2
		Lagoon	ST	18	ng NH3/cm2-s				16	Zahn et al., 2001	2
		-	ST	4.35	g NH3/m2-day				4.4	Hobbs et al., 1999	2
		Uncovered, no crust	ST	4.3	g NH3-N/m2-day				5.2	Sommer et al., 1993	2
		Uncovered, with crust	ST	0.5 - 1.5	g NH3-N/m2-day				0.6 - 1.8	Sommer et al., 1993	2
		Uncovered, with straw	ST	0.2 - 1.0	g NH3-N/m2-day				0.25 - 1.2	Sommer et al., 1993	2
		Capped with lid	ST	0 - 0.3	g NH3-N/m2-day				0 - 0.36	Sommer et al., 1993	2
		Deep-pit or pull-plug	VA	66	ng NH3/cm2-s			311	57	Zahn et al., 2001	2
		Earthen, concrete, or steel-lined	ST	167	ng NH3/cm2-s				144	Zahn et al., 2001	2
		Non-phototrophic lagoons	ST	109	ng NH3/cm2-s				94	Zahn et al., 2001	2
		Phototrophic lagoons	ST	89	ng NH3/cm2-s				77	Zahn et al., 2001	2
		Mechanically ventilated	VA	20 - 55	ug NH3/m2-s			10 - 26		Zhu et al., 2000	2
		Naturally ventilated, pit fans	VA	60 - 170	ug NH3/m2-s			28 - 80		Zhu et al., 2000	2
		Slurry removed weekly	VA	11	kg NH3/AU-yr			30		Osada et al., 1998	2
		Deep-pit manure storage	VA	11.8	kg NH3/AU-yr			32		Osada et al., 1998	2

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Swine	Houses	-		36.0	% NH3-N loss	11				Bowman et al., 1997	3, 4, 5
Pigs	Nursery	-	VA	700 - 1,200	mg NH3/pig-day			19 - 33		Aarnink et al., 1995	2
		Mechanically ventilated	VA	20 - 140	ug NH3/m2-s			23 - 160		Zhu et al., 2000	2
		-	VA	649 - 1,526	mg NH3/AU-h			16 - 37		Groot Kooerkamp et al., 1998	2
Pigs	Finishing	Nursery-to-finishing	VA	70 - 210	g NH3/h			66		Hinz and Linke, 1998	2
Pigs	Gestation	Mechanically ventilated	VA	5	ug NH3/m2-s			2.2		Zhu et al., 2000	2
Pigs	Sows	on bedding	VA	744 - 3,248	mg NH3/AU-h			18 - 78		Groot Kooerkamp et al., 1998	2
		on slats	VA	1,049 - 1,701	mg NH3/AU-h			25 - 41		Groot Kooerkamp et al., 1998	2
Pigs	Farrowing	Mechanically ventilated	VA	20 - 55	ug NH3/m2-s			15 - 42		Zhu et al., 2000	2
Pigs	-	Surface applied, urine only	LA	700	g NH3/hectare-h				70	Svensson, 1994	2
Pigs	-	Surface applied + immediate cover, urine only	LA	120	g NH3/hectare-h				12	Svensson, 1994	2
Dairy	Scrape Barn	-		8.9	kg/500 kg/yr	23.7				Demmers et al., 2001	1
		-		7 - 13	g/LU/day	9.7				Jungbluth, 1997	1
		-		8.3	g/N/cow/day	8.1				Misselbrook et al., 1998	1
		-		14.5	kg/animal/yr	32.0				Van Der Hoek, 1998	1
		-		AVERAGE		18.5				Calculated by EPA	1
Dairy	Dry lots	-		8.3	g N/cow/day	8.1				Misselbrook et al., 1998	1
		-		8	kg/cow/yr	17.6				USDA, 2000	1
		-		30	lb/head/yr	30.0				USDA, 2000	1
		-		AVERAGE		18.58				Calculated by EPA	1
Dairy	-	-		28	kg-NH3/animal-yr					Battye et al., 2003	3
	Stable*	-		36	% NH3-N loss		50			Bowman et al., 1997	1, 3, 4, 5
	Meadow	-		8	% NH3-N loss		30			Bowman et al., 1997	3, 4, 5
	Total	-		25.5	% NH3-N loss		80			Bowman et al., 1997	3, 4, 5

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Dairy	Manure Storage Tanks	-		6.6	% of N					Safely, 1980	1
Dairy	Solid Storage	-		20 - 40	% N lost					Sutton et al., 2001	1
Dairy	-	On bedding	VA	260 - 890	mg NH3/AU-h			6.2 - 21.4		Groot Kooerkamp et al., 1998	2
Dairy	Free-stall	-	VA	843 - 1,769	mg NH3/AU-h			20 - 42.5		Groot Kooerkamp et al., 1998	2
		Manure slatted floor	ST	400	mg NH3/m2-h				9.6	Kroodsma et al., 1993	2
		Scraped slatted floor	ST	380	mg NH3/m2-h				9.1	Kroodsma et al., 1993	2
		Unstirred slurry below slats	ST	320	mg NH3/m2-h				7.7	Kroodsma et al., 1993	2
		Stirred slurry below slats	ST	290	mg NH3/m2-h				7	Kroodsma et al., 1993	2
		Manure solid floor	ST	670	mg NH3/m2-h			16		Kroodsma et al., 1993	2
		Scraped solid floor	ST	620	mg NH3/m2-h			15		Kroodsma et al., 1993	2
		Flushed solid floor	ST	210	mg NH3/m2-h			5		Kroodsma et al., 1993	2
		-	ST	4	ug NH3/m2-s			0.35		Zhu et al., 2000	2
Dairy	Manure Land Application	Liquid (>200 head)		20	% N lost					Calculated by EPA	1
		Liquid (100 - 200 head)		22	% N lost					Calculated by EPA	1
		Liquid (<100 head)		24	% N lost					Calculated by EPA	1
		Solid (>200 head)		17	% N lost					Calculated by EPA	1
		Solid (100 - 200 head)		18	% N lost					Calculated by EPA	1
		Solid (<100 head)		19	% N lost					Calculated by EPA	1
Cattle	Dry lots	-		35 - 50	lb/day/1000 head	15.5				Grelinger, 1997	1
		-		0.76 - 2.82	g N/head/hour	42.0				Hutchinson et al., 1982	1
		-		18	lb/head/yr	18.0				USDA, 2000	1
		-		AVERAGE		25.2				Calculated by EPA	
Nondairy Cattle	Stable*	-		36	% NH3-N loss		15			Bowman et al., 1997	1, 3, 4, 5
	Meadow	-		8	% NH3-N loss		30			Bowman et al., 1997	3, 4, 5
	Total	-		17.3	% NH3-N loss		45			Bowman et al., 1997	3, 4, 5

Table 3-2 (continued)

Animal	Type	Notes		E.F.	E.F. Units	lb NH3/yr/head	kg N/head/yr	g NH3/AU-day	g NH3/m2-day	Original Source	Studies Included In
Beef and heifers	Liquid Manure	Land Application		20	% N lost					Calculated by EPA	1
	Solid Manure	Land Application		17	% N lost					Calculated by EPA	1
	Storage Pond	-		20	% N lost					Calculated by EPA	1
Beef	-	-		10.2	kg-NH3/animal-yr					Battye et al., 2003	3
	-	On bedding	VA	431 - 478	mg NH3/AU-h			10.3 - 11.5		Groot Kooerkamp et al., 1998	2
	-	On slats	VA	371 - 900	mg NH3/AU-h			9 - 21.6		Groot Kooerkamp et al., 1998	2
	-	On chopped straw	ST	547	mg NH3/m2-h				13	Jeppsson, 1999	2
	-	On unchopped straw	ST	747	mg NH3/m2-h				18	Jeppsson, 1999	2
	-	On chopped straw + peat	ST	319	mg NH3/m2-h				8	Jeppsson, 1999	2
	-	Uncovered, no crust	ST	4.5	g NH3-N/m2-day			5.5		Sommer et al., 1993	2
	-	Uncovered, with crust	ST	1.3	g NH3-N/m2-day			1.6		Sommer et al., 1993	2
	-	Capped with lid	ST	0.2 - 0.4	g NH3-N/m2-day			0.25 - 0.5		Sommer et al., 1993	2
Calves	-	On bedding	VA	315 - 1,037	mg NH3/AU-h			7.6 - 25		Groot Kooerkamp et al., 1998	2
	-	On slats	VA	1,148 - 1,797	mg NH3/AU-h			28 - 43		Groot Kooerkamp et al., 1998	2
Sheep	All Types	-				7.43				Calculated by EPA	1
	-	-		1.34	kg-NH3/animal-yr					Battye, et al., 2003	3
	Stable*	-		28	% NH3-N loss		1			Bowman et al., 1997	3, 4, 5
	Meadow	-		4	% NH3-N loss		9			Bowman et al., 1997	3, 4, 5
	Total	-		6.4	% NH3-N loss		10			Bowman et al., 1997	3, 4, 5
Goats	All Types	-				14.1				Calculated by EPA	1
	Stable*	-		28	% NH3-N loss		1			Bowman et al., 1997	3, 4, 5
	Meadow	-		4	% NH3-N loss		8			Bowman et al., 1997	3, 4, 5
	Total	-		6.4	% NH3-N loss		9			Bowman et al., 1997	3, 4, 5
Horses	All Types	-				26.9				Calculated by EPA	1
	-			8.0	kg-NH3/animal-yr					Battye, et al., 2003	3

* Emissions from stables include those from animal waste stored outside the stable and from spreading of animal waste.

Abbreviations Used in Table 3-2

AU = Animal Unit, LW = Live Weight, VA = Ventilated Area, ST = Storage, LA = Land Application

Codes for "Studies Included In" in Table 3-2

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2. Iowa Concentrated Animal Feeding Operations Air Quality Study. Iowa State University and The University of Iowa Study Group, February 2002.
3. Research and Development of Ammonia Emission Inventories for the Central States Regional Air Planning Association. Coe, Dana L., and Stephen B. Reid, 2003.
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Author(s)	Year	Article/Study
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Table 3-3: Odor Emission Factors

The emission factors in this table are given in odor units (OU) and detection thresholds (DT).

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Ireland	Finish	36	Partial Slats Mech. Vent	1	1	7.7	4.3-13	OU/s-pig	1
Swine	Ireland	Finish	36	Partial Slats Mech. Vent	1	1	6.0	3.5-9.0	OU/s/pig	1
Swine	Ireland	Dry Sows	300	Full Slats Mech. Vent	1	1	12	10.7-14.7	OU/s-pig	1
Swine	Ireland	Dry Sows	1300	Full Slats Mech. Vent	1	1	10.9	5.6-23.0	OU/s-pig	1
Swine	Ireland	Weaners	NA 5-20kg	Full Slats Mech. Vent	1	1	4.7	3.2-7.1	OU/s-pig	1
Swine	Ireland	Weaners	NA 20-25kg	Full Slats Mech. Vent	1	1	11.2	7.4-14.7	OU/s-pig	1
Swine	Ireland	Finish	NA 35-95kg	Full Slats Mech. Vent	1	1	8.5	2.5-29.6	OU/s-pig	1
Poultry	Ireland	Broilers	21,000	Solid floor, wood shaving Nat. Vent	1	2	0.45		OU/s-bird	1
Poultry	Ireland	Broilers	20,000	Solid floor, wood shaving Nat. Vent	1	2	0.55		OU/s-bird	1
Poultry	Ireland	Broilers	254,000	Solid floor, wood shaving Nat. Vent	1	2	0.46		OU/s-bird	1
Poultry	Ireland	Layers	12,500	Auto manure removal Mech. Vent	1	2	0.43		OU/s-bird	1

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine Storage	MN	Finish	2,000	Lagoon (crusted)	NA	3	7.3		$OU/s\text{-}m^2$	2
Swine Storage	MN	Finish	3,000	Lagoon	NA	3	20.8		$OU/s\text{-}m^2$	2
Swine	Ohio	Finish	960	High Rise	2	4	6.2	0.3-11.1	$OU/s\text{-}m^2$	3
Swine	Ohio	Finish	1000	Deep Pit, Tunnel Vent	2	4	34.2	3.7-91	$OU/s\text{-}m^2$	3
Bovine	NE	Feeders	2,000	Feedlot—April	3	3	6.1		$DT/s\text{-}m^2$	4
Bovine	NE	Feeders	2,000	Feedlot—June	3	3	4.1		$DT/s\text{-}m^2$	4
Bovine	NE	Feeders	2,000	Feedlot—August	3	3	3.9		$DT/s\text{-}m^2$	4
Bovine	NE	Feeders	2,000	Feedlot--September	3	3	2.3		$DT/s\text{-}m^2$	4
Bovine	MN	Calves		Open lot, scrape	2	3	16.5		$OU/s\text{-}m^2$	6
Bovine	MN	Steers		Open lot, scrape	2	3	4.4		$OU/s\text{-}m^2$	6
Bovine	MN	Dairy		Open lot, scrape, deep pit	2	3	1.3		$OU/s\text{-}m^2$	6
Bovine	MN	Heifers		Open lot, scrape, pull plug	2	3	3.0		$OU/s\text{-}m^2$	6

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Poultry	MN	Broilers		Loose, caged Mech. Vent	2	4	0.45		OU/s-m^2	6
Poultry	MN	Layers		Loose, Caged, scrape, Mech. Vent	2	4	3.45		OU/s-m^2	6
Poultry	MN	Turkeys		Loose, Scrape, Mech. Vent	2	4	0.32		OU/s-m^2	6
Swine	MN	Gestation		Crates, Pull plug, deep pit, Mech. Vent	2	4	12.6		OU/s-m^2	6
Swine	MN	Farrow		pens, crates, pull plug, scrape, Mech. Vent	2	4	4.8		OU/s-m^2	6
Swine	MN	Nursey		Pens, crates, pull plug, deep pit. M and N Vent	2	4	8.66		OU/s-m^2	6
Swine	MN	Finish		Loose pens, flush, pull plug, scrape, deep pit N and M Vent	2	4	6.86		OU/s-m^2	6
Swine	MN	Boars		pens, scrape, Natural Vent	2	4	5.73		OU/s-m^2	6
Swine	MN	Gilts		Pens, deep pit Mech. Vent	2	4	2.89		OU/s-m^2	6
Swine	MN	G/F/N		crates, pull plug, Mech. Vant	2	4	0.25		OU/s-m^2	6
Swine	MN	Wean to Finish		Pens, deep pit, Nat. Vent	2	4	7.0		OU/s-m^2	6
Poultry	MN	Broilers	50,000	Mech. Vent	2	4		0.2-0.4	OU/s-m^2	5

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	MN	Gestation	550 204 kg	Mech. Vent	2	4		4.8-21.3	OU/s-m^2	5
Swine	MN	Farrow	26 205kg	Mech. Vent	2	4		3.2-7.9	OU/s-m^2	5
Swine	MN	Nursery	475 20.5kg	Mech. Vent	2	4		7.3-47.7	OU/s-m^2	5
Swine	MN	G/F	550 81.8kg	Mech. Vent	2	4		3.4-14.9	OU/s-m^2	5
Swine	MN	G/F	400 109.1kg	Natural Vent	2	4		3.5-11.3	OU/s-m^2	5
Bovine	MN	Dairy	670	Nat. Vent	3	2		2-3	OU/s-m^2	7
Bovine Storage	MN	Feeders	670	Nat. Vent	3	3		7-10	OU/s-m^2	7
Swine	MN	Finish	180 82kg	Hoop Barn Winter	2	2		1.75	OU/s/pig	8
Swine	MN	Finish	950 105kg	Curtains, Winter Mech and Nat. Vent	2	2		4.74	OU/s-pig	8
Swine	MN	Finish	180 107kg	Hoop Barn Summer	2	2		11.67	OU/s-pig	8
Swine	MN	Finish	1000 88kg	Curtains, Summer Mech. and Nat. Vent	2	2		24.0	OU/s-pig	8
Swine	Netherlands	Finish		Partially Slatted	4	1	23.8	15.2-31.4	OU/s-pig	9

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Netherlands	Finish		Cooled surface of stored slurry below slats	4	1	19.4	10.8-28.3	OU/s-pig	9
Swine	Netherlands	Finish		Flushing system below slats done 2x/day	4	1	13.1	10.9-15.7	OU/s-pig	9
Swine	Netherlands	Weaned		slatted floors	4	1	6.8	4.0-16.3	OU/s-pig	9
Swine	Netherlands	Weaned		Cooled surface of stored slurry below slats	4	1	9.9	9.4-10.4	OU/s-pig	9
Swine	Netherlands	Weaned		Flushing system below slats done 2x/day	4	1	5.4	4.5-6 6	OU/s-pig	9
Swine	Netherlands	Nursery		Wire floors, Mech. Vent	5	4	1.76		OU/s-m^2	10
Swine Storage	Australia	Finish		Lagoon Summer	6	3		7.1-24.5	OU/s-m^2	11
Swine Storage	Australia	Finish		Lagoon Summer	6	3		12.0-24.5	OU/s-m^2	11
Swine	OK	Finish	6,000	Flush Pits/Lagoon	NA	5	18		OU/min-pig	12
Swine Storage	OK	Finish	6,000	Flush Pits/Lagoon (lagoon sampled)	NA	3		89-123	OU/min-m^2	12
Swine	Netherlands	Nursey					6.7		OU/s-m^2	13
Swine	Netherlands	Finish					19.2		OU/s-m^2	13

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Netherlands	Finish					13.7		OU/s-m^2	13
Swine	Netherlands	Sow					47.7		OU/s-m^2	13
Swine	Netherlands	Nursey						7.3-47.7	OU/s-m^2	14
Swine	Netherlands	Finish						3.4-11.9	OU/s-m^2	14
Swine	Netherlands	Farrow						3.2-7.9	OU/s-m^2	14
Swine	Netherlands	Gestation						4.8-21.3	OU/s-m^2	14
Poultry	Netherlands	Broilers					0.1-0.3		OU/s-m^2	14
Poultry	Netherlands	Layers					0.3-1.8		OU/s-m^2	14
Poultry	Australia	Broilers					3.1-9.6		OU/s-m^2	15
Swine	US	Finish		Daily flush			2.1		OU/s-m^2	16
Swine	US	Finish		Pull Plug			3.5		OU/s-m^2	16
Swine	US	Finish		Deep Pit			5.0		OU/s-m^2	17

Table 3-3 (continued)

Species	Location	Type	Size/ Number	Housing	Odor Method	Vent Method	Factor	Range	Units	Ref
Swine	Netherlands	Finish						6.7-47.7	OU/s-m^2	18
Swine	Netherlands	G/F		Mech. Vent				0.3-15.1	OU/s-m^2	19
Swine Application	Australia			Feedlot		3		128-160	OU/s-m^2	20
Bovine Application						3		937-22.7	OU/s-m^2	20
Bovine	Australia	Feeder						14-840	OU/s-m^2	21
Swine	Australia	Finishing		Flushing			150		OU/s-pig	22
Swine								0.25-12.6	OU/s-m^2	23

<u>Codes for "Odor Method" in Table 3-3</u>

1: 40ppb n-butanol for standards and 50% agreement among 8 panel members as the DT.
2: ASTM 679-91 and European Stand ODC 543.271.2-629.52
3: CEN Method 13725
4. Dutch Standard
5: CEN TC264
6: New Zealand Stand 4323.3

Codes for "Ventilation Method" in Table 3-3

1. Hot wire anemometer
2. CO_2 balance
3. Wind Tunnel (flux chamber)
4. Manufacturer specs
5. Heat balance

References for Table 3-3

1. E.T. Hayes et al. ASAE, Las Vegas Nev., July, 2003. Paper #034082.
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Table 3-4 – Particulate Matter (PM_{10}) Emission Factors

Species	Location	Type	Size/ Number/Units	PM10 Emission Factor Average/median	Range	Units	Reference
Beef	USA	Dry lot	500 animal unit (au)	12.7 lb/yr/au	5.4-20.0	lb/yr/au	1, 2
Dairy	USA	Dry lot	500 au	2.3 lb/yr/au	N/a		1
Swine	USA	Flush house	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Swine	USA	House w/pit recharge	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Swine	USA	House w/pull plug pit	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Swine	USA	House w/pit storage	500 au	8.0/8.8 lb/yr/au	4.6-13.0	lb/yr/au	3, 4
Poultry Chicken	USA Europe	Broiler house w/bedding	500 au	8.2 lb/yr/au	2.9-14.0	lb/yr/au	5, 6
Poultry Turkey	USA Europe	Turkey house w/bedding	500 au	18.7/18.7 lb/yr/au	1.4-36.0	lb/yr/au	5, 6
Cattle	USA	Feed yards	1000 hd/d	15 lb/1000 hd/d			7
Dairy	USA	Free stall	1000 hd/d	4.4 lb/1000 hd/d			7
Swine	UK	Housed livestock		573 lbs/1000 hd			8
Dairy	UK	Housed livestock		284 lbs/1000 hd			8
Broilers	UK	Housed livestock		129.6 lbs/1000 hd			8
Beef	UK	Housed livestock		92.4 lbs/1000 hd			8
Poultry	UK	Housed livestock		163 lbs/1000 hd			8
Laying hens	UK	Housed livestock		42.8 lbs/1000 hd			8

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